THE IMPACT OF INFORMATION TECHNOLOGY ON ORGANIZATION

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Introduction

A discussion of the impact of information technology on organization is largely a matter of speculation, since we are just now beginning to perceive its effects. Speculation, though often interesting and occasionally useful, presents some obvious hazards.

One hazard, of course, is that predictions may prove wrong. This is not as great a danger as one might suppose, however, since the dramatic developments in the field of information technology make it likely that any prediction, if it is sufficiently imaginative and glamorous, will eventually prove correct. In any event, suitable hedging can minimize the probability of error, and faulty memories will reduce the penalty of an error if the prognosticator is indiscrete enough to make it obvious.

A more serious and immediate pitfall is that the speculation may be trite and commonplace. This hazard is particularly treacherous when discussing information technology and organization, since we already have been presented with such a rich abundance of speculation on the subject.[*] I do not claim that I have avoided this hazard altogether, but I have tried to reduce the risk by confining my discussion to some of the less explored issues involved.

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[*] Among the earliest and most perceptive, I think, is the work of Leavitt and Whisler (1958).

As I view the topic, information technology will affect organizational structure primarily through the improvements it brings in the planning process.

The role of planning within the organization*

An organization consists of a hierarchy of subunits pursuing a common set of objectives. Consistent, purposeful behavior on the part of all subunits is achieved through planning. The results of the planning are expressed in such forms as goals, plans, budgets, schedules, policies, and procedures.

Planning, like the organization itself, has a hierarchical structure. The total process is "factored" into a hierarchy of subsidiary processes. Planning at one level has as its purpose the achievement of plans formulated at the next higher level. Conversely, high-level planning aims at imposing constraints that lead to "good" lower-level planning that, in turn, eventually results in "good" organizational behavior. Higher-level planning thus affects behavior only indirectly through lower-level planning.

High-level planning generally deals with aggregate variables extending over relatively long time spans. Lower-level planning progressively adds greater detail within the constraints provided by the more aggregate plans. For example, a quarterly plant-wide schedule might be amplified by lower-level planning into weekly departmental schedules.

Planning at a given organizational level is constrained not only by current operating plans, but also by less ephemeral forms of higher-level

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*I have discussed the role of planning in a previous paper (1964) and so the remarks here provide only a sketch of that more detailed article.

planning. The goal structure of the organization, for example, serves this purpose. Thus, basic long-range "objectives" restrict the choice of medium-range "goals" that limit the choice of short-term "plans." Similarly, policies and procedures defined at one level in the organization provide constraints on lower-level planning (Granger, 1964). All of these forms of planning are, of course, designed to constrain lower-level planning in a way that will bring about satisfactory organizational behavior.

All lowest-level plans taken together describe the desired behavior. In order to do this with sufficient precision to make the description un-ambiguous (within "reasonable" tolerances), the composite lowest-level plan must ultimately contain a great deal of information. This information is expressed in the form of such high-resolution variables as scheduled daily production of each unit, number of employees of each skill classification, and detailed delivery schedules.

On the other hand, the aggregate, low-resolution variables used in high-level planning provide very much less information than the composite lowest-level plan. The information added in amplifying high-level plans into low-level plans must come from somewhere. It comes from the hierarchical planning process.

The design of this planning process represents a fundamental issue in managing an organization. The choice of the various constraints that impinge on planning involves a problem-solving process of the most complex sort. In order to break up the overall problem into manageable subproblems, the global

objectives of the organization are factored into subobjectives. This is done through a "means-ends" analysis that relates desired end results to the means of accomplishing them. The subproblems thus generated are, in turn, factored into still less comprehensive problems. This process continues until the subproblems become manageable without further factoring (March and Simon, 1958, pp. 190-193).

The behavior of the organization depends largely on the way in which the hierarchical factoring is accomplished. Unfortunately, there exists no known method for doing this in any "optimal" fashion. The structure of the factoring basically rests on the notion of what constitutes a "manageable" subactivity. If the global objectives of the organization were themselves economically manageable without fragmentation, then it would be optimal to perform no factoring. That organizations universally resort to hierarchical planning merely reflects their inability to cope with monolithic global objectives.

Thus, the factoring of global objectives into a hierarchy of subactivities is absolutely essential. However, in order to reap the benefit of the simplifications introduced by this fragmentation, each subactivity must be largely isolated from the rest. Otherwise, each manager would need access to information about all other activities with which his activity interacts, and in effect he would have to handle the global problem.

Independence among organizational units can be increased in several ways. The organizational structure itself plays an important role in this. Communication across hierarchical lines can be reduced--and hence independence increased--by grouping together within the same subunit those activities that

have a high degree of interaction (as is done, for example, in a "project"
organizational structure). Interactions caused by the flow of physical in-
puts and outputs among subunits can be reduced through various means of
"decoupling," such as standardization of specifications, use of buffer in-
ventories, and maintaining excess resources within each subunit. Finally,
apparent independence is achieved to a considerable extent by simply ignoring
the less significant interactions.

These devices for achieving greater independence carry a price. The
price is paid in the form of forgone opportunities for greater speciali-
zation (achieved, for example, in a "functional" organizational structure);
in the higher manufacturing costs associated with closer tolerances; in the
cost of acquiring and maintaining buffer inventories; in lower resource
utilization; and in the penalties of suboptimization that result from ignoring
interactions (Hitch, 1953; Hitch and McKean, pp. 125-133 and 158-181).

A partial trade-off exists between these costs and the costs of co-
ordination. With closer coordination, activities can be coupled more directly,
and therefore the costs of achieving greater independence can be correspondingly
reduced. But coordination, too, exacts a price. It costs money in the form
of data collection, data transmission, computation, and--often the most im-
portant cost--the effort required to design the information system that achieves
closer coordination. Organizational structure implicitly reflects a choice of
the economic balance between greater independence and greater coordination.

Coordination is achieved primarily through the planning process. Planning

necessarily relies on an abstract model of the real world whose activities are being planned.[*] The plans that emerge describe coordinated actions to the extent that the model recognizes significant interactions and has access to sufficient information about the predicted behavior of other subunits.

The effect of information technology on planning

This brings me to the central issue of this paper. Factoring of the global objectives of the organization depends heavily on the current state of information technology.[**] Information technology affects organizational structure by permitting an increase in the scope of the activities falling within a given subunit. As the organization gains enhanced ability to manipulate information, the permitted size of a "manageable" task expands. Global objectives therefore need not be fragmented as finely as before, and the number of organizational subunits can be correspondingly reduced.

Increasing each subunit's "span of control" mitigates the problem of coordination among the subunits. Activities that formerly involved strong interactions among different units may now be included within a single comprehensive unit. Such consolidation obviously reduces the interactions among subunits and permits closer coupling of previously decoupled activities.

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[*]The "models" may be formalized mathematical or computer models or--more often--a simplified, abstract mental image of the world that the planner necessarily resorts to in exercising his judgment and intuition.

[**]Subsumed under the broad term of information technology are the more restricted fields of operations research and the computation sciences.

This phenomenon has already manifested itself to a considerable extent--particularly in the field of production and inventory control--and will doubtlessly become all the more evident in the future.

The trend toward increasingly comprehensive activities will certainly not eliminate the need to parcel out the organization's global activities among different subunits. The interactions that inevitably result from such fragmentation will still call for various measures to increase the real or apparent independence among the subunits. However, the advances made in information technology move the economic balance between independence and coordination sharply toward the latter. Like any other factor of production, a manager should employ more information handling as its cost declines.

Advances in information technology permit greater formalization of planning. Analytical or simulation models can often take the place of intuitive models. Analytical models typically permit manipulation aimed at finding the "optimum" of an objective (or criterion) function. This is obviously useful when an available model captures the essential character of the real world and when the model can be optimized by a computationally feasible algorithm. Very often, however, these conditions do not obtain, and one must resort to brute force simulation techniques.

In either case, the models provide a prediction of outcomes stemming from planned actions. The planner can continue to examine alternative plans until he judges that the cost of further search exceeds the expected improvements that would result. Even when he has available an "optimizing" model,

the planner may wish to explore for improved plans that recognize factors not considered in the formal model.

Man-machine planning systems

Man-machine systems offer exciting possibilities for improving decision processes. The meager evidence that we have suggests that a symbiosis between the man and the machine will prove especially powerful and fruitful in coping with the enormously complex problems encountered in organizational planning. To the human component in such a system is relegated the responsibility for proposing alternative plans and judging the suitability of their consequences. The machine is assigned the computational task of transforming proposed actions into their consequences by means of a formal model.

The great advantage of man-machine systems is that they do not require the complete formalization of the decision process. Those decisions that are well understood and capable of being described formally can be incorporated into the computer model. Decisions that cannot be so formalized are simply reserved for the human decision maker.

A planner armed with a man-machine system can use it to explore in depth for improved plans. A sequential, hierarchical search appears particularly efficient (Dalkey, 1962; Emery, 1964). Using an aggregate model, the planner can search for a superior high-level plan. Each probe in the "space" of alternatives provides information useful to him in proposing further probes. He continues his search until a satisfactory high-level plan is found.

The aggregate plan emerging from such a process is then amplified by

more detailed models. A search at a lower level is similar to the high-level search except that it is constrained by higher-level plans previously selected.[*] These constraints explicitly recognize interactions among the detailed models, and hence they can reduce the penalties of suboptimization. Furthermore, the constraints confine the range of alternatives that need to be examined at the more detailed level, thereby enormously increasing the efficiency of the search process (at the possible risk, however, of overlooking attractive detailed plans that do not meet the imposed constraints).

The sequential, hierarchical search process continues until the most detailed plan contains sufficient information for its execution. Execution, as far as a high-level manager is concerned, normally involves passing the high-level plan to the next lower level of management. The planner at the lower level may go through a similar man-machine search as part of the planning required at his level.

From this description it should be apparent that man-machine planning is completely analogous to the conventional planning process. The chief difference is that a man-machine planning system employs a hierarchy of formal models under the direct control of the planner, rather than using the organization itself as a hierarchy of informal models. Such a system allows the high-level planner to obtain consistent, detailed, rapid, and relatively inexpensive evaluations of proposed alternatives.

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[*]Higher-level plans may, however, require iterative modification as a result of the detailed analysis performed by lower-level models.

Because of its speed and reduced cost, man-machine planning can be per-
formed frequently and many alternatives can be considered during each planning
cycle. Improved plans will presumably emerge from an expanded search. Further-
more, an unrealistic high-level plan can be explicitly identified during the
detailed amplification by lower-level models. As a result, the high-level
planner can immediately make appropriate modifications to his plan. In con-
ventional systems, such modification may not be made until long afterwards,
during attempted execution of the unrealistic plan.

Centralization versus decentralization

A great deal has been written about the effect of information technology
on the issue of centralization versus decentralization. Unfortunately, differ-
ent authors come to diametrically opposite conclusions, and so it is difficult
to judge where the concensus lies.

At least part of the difference of opinion stems from the lack of a
precise definition of "centralization."[*] Such a definition should, I think,
recognize the sources of the information gained during the hierarchical
planning process. Let me propose a tentative definition that does take this

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[*] For example, one reads arguments to the effect that computers will lead to
decentralization because they will allow top management to monitor more closely
the operations of lower-level management. If close surveillance serves any
purpose at all, this means that top management will be in a position to judge
the detailed actions of subordinates. Presumably, a lower-level manager can
exercise freedom of action as long as he takes the "right" actions as judged
by his superiors. It seems to me that any reasonable definition would have
to include such Orwellian surveillance as an aspect of centralization.

factor into account.

In amplifying higher-level plans into lower-level plans, each organizational unit adds information. In a "centralized" organization, most of the information comes from the higher levels; in a "decentralized" organization, the lower levels tend to supply a relatively greater proportion of the information.

Information content is a function of the selectivity of the information. If a given manager in the organization has only a few options open to him, then the specific plan he chooses has a relatively low information content. This is so because the plan selects one course of action from the small number of alternatives available. In the extreme case where a manager can pursue only a single course of action, the planning process at his level adds no information at all.[*] If, on the other hand, there exists a large number of alternative ways of amplifying higher-level constraints into lower-level plans, then planning at this level adds a great deal of information because it has the power to select one plan out of many options.

Some specific examples might make this concept clearer. Consider a plant scheduler. If his activities are severely constrained by policies, standard operating procedures, and higher-level schedules, then he has relatively little opportunity to exert much freedom of choice. At least as far as he is con-

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[*] A certain amount of amplification of a higher-level plan might take place, but if the amplification is completely determined by procedures specified by higher-level managers, then no real alternatives exist. The amplification thus does not add any information not already implicit in the higher-level planning.

cerned, he lives within a centralized organization.

A different organization might leave the scheduler much greater dis-
cretion. He might, for example, be given a monthly schedule by major product
line, without further specification as to how the detailed scheduling is to
be performed. With such loose central direction, he could choose any of a
vast number of possible detailed schedules, all of which are perfectly con-
sistent with high-level constraints. His choice of a specific schedule
therefore has a high power of selection and hence a high information content.
Accordingly, the organization to him appears decentralized.

My definition of centralization obviously lacks rigor. It also has
several other possible drawbacks. The most glaring one is that it does not
provide an operationally measurable criterion of centralization. In most
cases it would be impossible--or, at best, extraordinarily difficult--to de-
termine the number of low-level plans that are consistent with a given high-
level plan. Nevertheless, the fact that the definition is not operational
need not rule out its use.*

Perhaps a more serious deficiency in the definition is that it fails
to take into account the relative importance of information added at different
levels in the organization. For example, centralization might be defined
in terms of the range in value of alternative plans available at a given organ-
izational level. However, such a definition requires a means of assessing
the "value" or "utility" of alternatives. This obviously raises some very

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In any case, I have not seen any other definitions of centralization that
eliminate this problem.

formidable conceptual problems, to say nothing of the practical ones.* If, in fact, the ordinal utility of alternative plans were known, then the choice among alternatives would be straightforward and could just as well be made by a centralized agency. That this is not the case provides the chief justification for decentralization.

Furthermore, the advantage of introducing utility into the definition of centralization is not at all clear. A manager presented with a simple choice between two alternatives having widely differing (but unknown) utilities might feel much more a victim of centralization than a manager faced with a choice from among a large number of alternatives differing only insignificantly in utility.

Despite its shortcomings, the proposed definition has, I think, several desirable properties that make it suitable for the purpose at hand. For instance, it recognizes the relative nature of centralization and makes explicit the fact that centralization occurs to some extent throughout the entire organization. An organization may be highly "decentralized" at the highest levels and "centralized" at the lower levels. Thus, a given division may be autonomous and decentralized within the organization as a whole, but relatively centralized within itself. Some of the well-known "decentralized" firms seem to fall within this class. Notwithstanding often expressed opinion

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*The definition of centralization in terms of the selectivity of a plan instead of the range of its values is analogous to Shannon's definition of information in terms of its selectivity rather than its semantic content.

to the contrary, the Defense Department manifests this same tendency.[*]

The proposed definition of centralization also appears to be quali-
tatively reasonable. If a higher-level manager imposes additional constraints
that reduce the number of lower-level alternatives, this would normally be
considered a move toward greater centralization. Conversely, changes that
are generally recognized as leading toward centralization typically result
from higher-level constraints that reduce the number of alternatives available
at lower levels. The polar case of complete centralization, where the highest
level in the organization generates all planning information and leaves no
options for lower-level managers, would surely be considered complete central-
ization by any definition.

After this somewhat lengthy digression to define terms, I am now in a
position to discuss the effect of information technology on centralization.
It seems to me that the available evidence clearly supports the view that
advances in information technology will lead toward greater centralization.
These advances certainly permit the organization to store, retrieve, and
manipulate greater quantities of data then ever before. There is no reason
to suppose that high-level managers will not exploit this capability. Nor
is there a clear case to suggest that they should not.

As Leavitt and Whisler pointed out (1958, p. 43), decentralization has

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[*] Professor Billy Goetz of M.I.T. has observed (not altogether in jest) that
most managers prefer an organization that is decentralized from the top
down to them, and centralized thereafter.

been largely negatively motivated. In conventional systems, high-level management has no choice but to leave considerable freedom for lower-level management. The establishment of realistic detailed constraints requires access to a great deal of information, and until recently such information was hopelessly beyond the data handling capacity of high-level management.

High-level planning, like planning at any level, involves a search for a satisfactory plan among the alternatives available. Using conventional methods, high-level planners must conduct this search based on grossly simplified and aggregated models of the real world. Under these circumstances, a high degree of centralization is usually quite rightly regarded as mischievous meddling in detailed matters well beyond the low-resolution information available at the higher levels in the organization.

Advances in information technology blunt the force of this argument against more centralized planning. An increased data handling capability permits high-level planners to develop and manipulate much more detailed and comprehensive formalized models than can be handled by conventional planning techniques. This offers two advantages.

First, detailed plans can be made more realistic and consistent. Comprehensive models submerge relatively little important information from the view of the high-level planner. As a result, he is less likely to impose infeasible constraints on lower-level planners. Consequently, the lower-level planners need less flexibility in order to compensate for the high-level planner's lack of information about their operations.

Second, detailed plans generated through complex analytic or simulation models can lead to improved organizational performance. The increased comprehensiveness of such formalized planning models makes it possible to consider more of the interactions that occur among lower-level subunits, thus reducing the penalties associated with suboptimization.

The effect of greater centralization on middle managers

To be sure, persuasive counterarguments can be mustered against greater centralization. Many persons may agree that there exists a clear trend toward centralization, but find the prospect both dreary and frightening. With Dr. Malik, they view such a world as having "perfect hierarchy, perfect organization, total efficiency; but no spirit, no freedom, no joy, no humor, and therefore no man." (Malik, 1963).

It is, of course, exceedingly difficult to assess the effect of greater centralization on the human beings composing an organization (and I certainly claim no special competence to do this myself). Nevertheless, a case can be made against the more gloomy predictions about man's role in a centralized organization. In trying to do this, I will focus attention on middle managers, since they are the ones that appear most vulnerable and have the most to loose from centralization.

A manager working in the middle of a large bureaucratic organization faces several possible perils. One of these is that severe constraints might be imposed on him, stifling his initiative and robbing his job of all challenge and interest. This is the risk that probably weighs most heavily in the minds

of those that decry centralization.

But the world of a manager at any level is enormously complex, and there seems little possibility that it need ever loose its zest. Most managers confront a set of multidimensional goals and a probabilistic environment that can never be fully captured by "optimizing" models. As we gain competence in dealing with various aspects of this world, our ignorance may diminish but still remains everlastingly vast. There probably exists a Parkinsonian law to the effect that the complexity of a manager's job expands to meet his ability to cope with complexity.

Under the definition that I have adopted, it is certainly true that greater centralization imposes additional constraints on a lower-level manager. On the other hand, information technology permits him to explore in greater detail the reduced space of alternatives left available to him. As a result, the number of discernible alternatives open to him may be very much greater than in a conventional planning system. The number of perceived alternatives, rather than the potential ones, may well represent the important psychological criterion that a manager uses in judging the scope and challenge of his job. Thus, information technology may lead to the paradoxical situation of giving managers at all levels greater effective freedom of action.

In any case, lack of alternatives is not the only problem facing the middle manager. Probably at least as great a peril is an overabundance of alternatives without a suitable means of selecting among them. Such excessive freedom of choice often breeds nothing but chaos, and one need not envy a

manager placed in this position. Indeed, he might well greet a few judicious higher-level constraints with unalloyed relief.

More than one manager of production scheduling, for example, has welcomed the constraints on his job represented by a computer scheduling program. Instead of continual ad hoc "fire-fighting," these managers can, for the first time, focus attention on improving the planning process itself (perhaps by helping to incorporate improved algorithms in a computer program). Many of them also find more time for the non-planning and human relations aspects of their job.

Still another problem facing a middle manager is the risk of being assigned unreasonable and unrealistic plans. As discussed earlier, the quality of these plans is largely a function of the data handling capacity available to his higher-level managers. One of the most serious indictments against many of the current centralized planning schemes is that the constraints they impose are not based on a sufficiently realistic model of the world, nor on adequate information about the current state of that world. A lower-level manager naturally finds it difficult to work under such conditions. Advances in information technology eliminate much of this problem. As a result, lower-level managers may have less justification to mistrust the centralization induced by these advances.

Conclusions

There seems to be little doubt that the rapid strides being made in information technology will improve high-level planning. A more accurate, timely,

and accessible data base will provide a better analogue of the current state of the environment with which to predict planning data. Formalized analytic and simulation models will permit more realistic predictions of the consequences of alternative actions. The increased speed of evaluating proposed alternatives will allow a wider search for improved plans.

The plans that emerge from such high-level planning will be more comprehensive, realistic, and detailed than can be generated by conventional means. Because of their greater information content, they will impose additional constraints on lower-level planners. By definition, this results in greater centralization.

The effect of these developments on a lower-level manager is not at all clear. It is by no means certain that his job will diminish in interest or challenge. It is at least possible that it will be made more attractive through a reduction of some of its uncertainty and many of its unrealistic demands.

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